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Influence of Flood Detention Capability in Flood Prevention for Flood Disaster of Depression Area

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Abstract**—**Rainfall records of rainfall station including the rainfall potential per hour and rainfall mass of five heavy storms are explored, respectively from 2001 to 2010. The rationalization formula is to investigate the capability of flood peak duration of flood detention pond in different rainfall conditions. The stable flood detention model is also proposed by using system dynamic control theory to get the message of flood detention pond in this research. When rainfall frequency of one hour rainfall duration is more than 100-year frequency which exceeds the flood detention standard of 20-year frequency for the flood detention pond, the flood peak duration of flood detention pond is 1.7 hours at most even though the flood detention pond with maximum drainage potential about 15.0 m^3/s of pumping system is constructed. If the rainfall peak current is more than maximum drainage potential, the flood peak duration of flood detention pond is about 1.9 hours at most. The flood detention pond is the key factor of stable drainage control and flood prevention. The critical factors of flood disaster is not only rainfall mass, but also rainfall frequency of heavy storm in different rainfall duration and flood detention frequency of flood detention system.

Keywords**—**Rainfall frequency, Rainfall duration, Rainfall intensity, Flood detention capability

I. Introduction

HEAVY storm plays an important role in flood disaster event. Once the rainfall potential is more than the drainage capability of river and drainage system, the water without draining will flow over. Both in 2001 and 2010, two typhoons result in serious flood disasters at urban depression area at Benhe Villiage, Kaouhsiung, Taiwan. The flood detention pond had been constructed previously before the latter typhoon. The causes of flood disaster will be proposed in this report. The flood detention capability of flood detention pond and the relationship between rain potential and flood disaster are also explored in this paper by using rainfall records in rainfall station. There are two research objects in this paper. Firstly, if the flood detention pond at the Benhe Villiage depression area had been constructed before 2001, whether flooded or not will be explored during Trami typhoon with heavy storm in 2001. Secondly, after flood detention pond had been constructed in 2004, there were no flood disasters of depression area as results of three heavy storm and typhoons from 2005 to 2009. However, flood disaster occurred once again in 2010 by Fanapi typhoon. Therefore, the cause of flood disaster after the flood detention pond constructed is also researched in this paper.

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II. Literature Research and Research Theory

A. *Rainfall intensity-duration-frequency theory*

In this research, firstly, definition of specialized subjects is progressed. The rainfall duration is defined by the continuous rainfall time. The rainfall intensity is stated by rainfall per unit in time. The rainfall frequency is the engendering frequency of specific rainfall intensity and rainfall duration. For example, 200-year frequency means that the rainfall intensity appeared per 200 years in average value. Flood prevention frequency is the quantity standard in a variety of hydrological phenomena [1]. For example, 200 years flood prevention frequency is illustrated that the rainfall intensity appears per 200 years in average value. The rainfall due to the 200 years flood prevention frequency will appear the characteristics of surface runoff, flood potential, and drainage capability. The flood prevention frequency is the basis of designing and constructing various hydraulic installations such as rain sewerage system, dykes, pump stations, etc.

Base on the survey of hydraulic department, the flood prevention and drainage in rain sewerage system is designed by the standards of rainfall frequency in once per five years and rainfall of 70.9 mm in one hour duration in Kaohsiung city. On the other word, if blocks of sewerage system and sink of watershed are eliminated, when the rainfall intensity is less than 70.9 mm in rainfall duration of one hour, the rainfall will be drained normally by the rainfall sewerage system in theoretical analysis. The rainfall intensity-duration-frequency of Kaohsiung city in unit of mm/hr is shown in Table 1 [2]. The rainfall intensity of 41.9 mm/hr in rainfall frequency of five years and rainfall duration of three hours is meaning that the probability of rainfall mass more than 125.7 mm is about 20% per rainfall duration of three hour in one year in Kaohsiung city. At the same rainfall duration, the more the rainfall frequency is, the more the rainfall intensity is, because of the high strong rainfall probability. The more the rainfall duration is, the less the rainfall intensity is at the same rainfall frequency. The rainfall mass (R_M) in the duration time is calculated by using the product of rainfall intensity (R_I) and rainfall duration (R_D), as expressed in equation (1).

$$R_M = R_D \times R_I \quad (1)$$

TABLE I
CHARACTERISTIC OF RAINFALL INTENSITY-DURATION-FREQUENCY IN KAOHSIUNG CITY. (UNIT: MM/HR) [2]

Rainfall intensity (mm/hr)		Rainfall frequency (year)						
		200	100	50	20	10	5	2
Rainfall duration (hour)	1	145	130	117	98	87	71	51
	2	120	106	91	76	62	53	35
	3	100	90	76	62	50	41	29
	4	91	80	66	53	42	33	25
	6	80	67	56	46	37	30	21
	12	52	45	38	31	26	21	15

B. *Fundamental of Flood detention pond*

A pond of flood detention collects part of rainfall runoff. It decreases flood peak and drain out rainfall suitably after the flood peak goes down. Part of collected flood permeating underground becomes the underground water source. The underground water is prepared water in dry season to conquer varied climate.

In this research, the selected researched area is the Benhe Village of Kaohsiung city. It is located at the cross area of SK sewerage trunk line, K sewerage strung line, and Golden Lion lake at Sanmin District. In this area, the flood disaster incidents usually occurred during typhoon periods or storm periods. Many places resulted in water-flooding in Kaohsiung city during Trami typhoon at July, 2001. The maximum depth of water-flooding reached 210 cm at Benhe Village. By the research and plan of Disaster Prevention Research Center in National Cheng Kung University, it suggested that the flood detention pond must be constructed to control the flood and drain the rainfall, and to solve the flood problem at Benhe Village. The Benhe Village is located at filled old Benguan lake where is now with buildings; therefore, it must be flooded by water in rainfall seasons. The flood detention capability of Benhe flood detention pond can reach 100,000 m^3. The pond can unravel the problem of rainfall frequency in about twenty years and drain water about 98 mm/hr in rainfall duration of one hour; so it can delay flood peak for about 2.3 hours. The operation fundamental of flood detention pond is stated as follows. Firstly, the regulating pond which is beside Benhe flood detention pond gathers the draining-water in rainfall sewerage system during rainstorm period and typhoon period. Secondly, the accumulated water in the regulating pond is pumped into flood detention pond by using mechanical pumps. After the rainstorm, as the water level of sewerage trunk line and river in city fall down, the accumulated water in flood detention pond is pumped into sewerage trunk line and then goes into river. The operation chart is shown in Fig. 1. The pump station possesses five mechanical pumps, which maximum pumping value of each pump is 3.0 m^3/s. Two of mechanical pumps are flexible, which can pump the water either from regulating pond to flood detention pond or from regulating pond into rainfall sewerage system. Since the flood detention pond is constructed, the water-flooding event didn't occur until 2010.

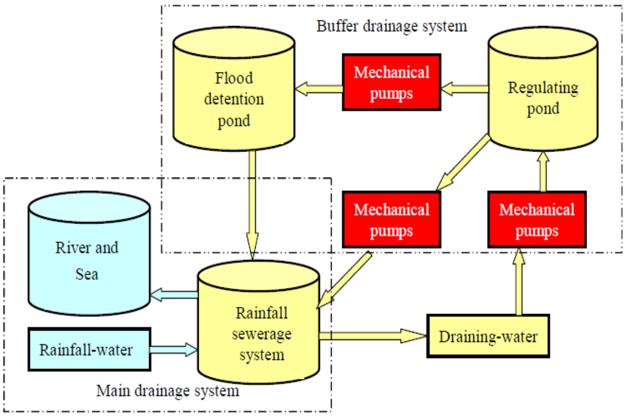

Fig. 1 The operation fundamental of Benhe flood detention pond

The peak current of every heavy storm period is calculated by using rationalization formula in differential rainfall duration and then the duration time of flood peak is obtained. When the watershed is less than 10 km^2 and rainfall time is equal to or larger than time of water concentration which is the time of water flow from the highest place of sloping field to the outer, the runoff potential in the watershed produces the maximum value [3]. In this situation, the rationalization formula which is usually used to design and analyze hydrologic event in hydrology can be applied to get peak current of water flow. The rationalization formula is expressed as follows in equation (2) [3]. In the equation, ***Q*** is defined by peak current with **cms** (m^3/s) in unit. ***C*** is the runoff coefficient which is defined by ratio between runoff potential (ROP) and rainfall potential (RFP) in without unit, as expressed in equation (3) [3]. The variable ***I*** is the average rainfall intensity with unit of mm/hr. ***A*** is the watershed area with unit of hectare. In this research, the watershed area of flood detention pond is about 51.2 hectare, which is in accord with the definition of small watershed as above.

$$Q = 0.00278 \times C \times I \times A \quad (2)$$

$$C = \frac{ROP}{RFP} \quad (3)$$

Because every continuous rainfall time of heavy storm in the past is further more than time of rain concentration, the rationalization formula can be applied in calculation of peak rainfall current.

C. *Determination of runoff coefficient*

The Benhe Village is located in watershed, which is developed with high population density. In this area, the earth's surface is covered by buildings and asphalt roads which are the impermeable surfaces for water. When the rainfall intensity is high, the rain directly forms runoff which will flow and accumulate into depression area. The runoff coefficient in different rainfall frequency is expressed in Table 2 for the researched area. Rainfall coefficients of every heavy storm periods are obtained by calculating the rainfall frequency in different rainfall duration as shown in Table 2 [2]. For example, if the heavy storm duration is two hours and the rainfall frequency is between 20-years and 50-years, then the runoff coefficient is about 0.87. The values of runoff coefficient and average rainfall intensity for every heavy storm period are substituted into formula (2) to calculate the peak current [4].

TABLE II
RUNOFF COEFFICIENT IN DIFFERENT RAINFALL FREQUENCY AT BENHE VILLAGE [2]

Rainfall frequency (year)	200	100	50	20	10	5	2
Runoff coefficient	0.97	0.95	0.90	0.87	0.85	0.77	0.73

D. *Determination of flood detention time*

The flood detention time ***T*** for the flood detention pond can be calculated by using the following formula, as expressed in equation (4), where ***V*** is volume of flood detention pond and ***Q*** is the peak current [5]. The maximum flood detention volume of flood detention pond is the product of peak current in unit of m^3/s and flood detention time in unit of hour [6].

$$V = 3600 \times Q \times T \tag{4}$$

The flood detention time ***T*** can be calculated by using average rainfall potential in heavy storm duration of ***N*** hours. When flood detention time is larger than heavy storm duration or equal to heavy storm duration, the rain water which is in fluxed from rain sewerage system can be contained by flood detention pond in the rainfall duration of N hours completely. In this situation, the rain water will not flow back to the ground to flood. Otherwise, when the flood detention time is less than heavy storm duration, although the rainfall time does not reach the rainfall duration in N hours, the flood detention pond will be full-load and it will not be able to defer the flood peak. Therefore, when the rain water of rain sewerage system can not be continuously drained into flood detention pond, the rain water will flow back to the ground to result in flood disaster.

III. RESEARCH METHOD

In this research, the rainfall data of hour by hour is collected and analyzed including Trami typhoon from July 11 to July 12 in 2001, heavy storm on June 12 in 2005, Kalmaegi typhoon on July 17 in 2008, Morakot typhoon from August 7 to August 8 in 2009, and Fanapi typhoon on September 19 to September 20 in 2010. The rainfall data is obtained by the measurement of rainfall potential at the nearest rainfall station--Zuoying rainfall station, where is at a distance from the flood detention pond about 4 km [2][7]. The relationship between heavy storms and flood disasters is studied in this paper. In this study, the maximum rainfall mass in continuous 24 hours is analyzed and discussed in each heavy storm event. By the rainfall record per hour, the maximum average rainfall potential is analyzed in rainfall duration of 1, 2, 3, 4, 6, 12 hours during heavy storms respectively and the rainfall frequency is obtained by calculating the data of Table 1. For instance, the average rainfall potential is between 2-5 years at the heavy storm duration of two hours and maximum rainfall mass of 85 mm. The rainfall records are exhibited in Table III.

There is an assumption which must be established in this study as following statement. When heavy storm and high tide occurred, the water level in river raised up abruptly. In this situation, the K sewerage strung line will lose the drainage capability. That is, the water can not be drained into the river. The assumption is that in each studied rainstorm event, water level of the K sewerage strung line always reached the highest value and water only flew into Benhe flood detention pond, but not flew out. In this assumption, we calculate flood detention capability of the Benhe flood detention pond in different rainfall conditions. That is, how long the Benhe flood detention pond reached the full load in different rainfall conditions.

TABLE III
FLOOD DISASTER, FLOOD DETENTION POND, AND RAINFALL RECORDS FROM RAINFALL STATION

Rainfall event	Rainfall date	Flood detention pond	Flood disaster
Trami typhoon	July 11-12, **2001**	**Without the pond**	**Flood**
The flood detention pond has been constructed in **2004**			
Mei-Yu heavy storm	June 12, **2005**	With the pond	In safety
Kalmaegi typhoon	July 17, **2008**	With the pond	In safety
Morakot typhoon	August 7-8, **2009**	With the pond	In safety
Fanapi typhoon	September 19-20, **2010**	With the pond	**Flood**

IV. RESULTS AND DISCUSSION

According to the rainfall records of Trami typhoon in 2001 (2001Trami), Mei-Yu Heavy storm in 2005 (2005Mei-Yu), Kalmaegi typhoon in 2008 (2008Kalmaegi), Morakot typhoon in 2009 (2009Morakot), Fanapi typhoon in 2010 (2010Fanapi) from rainfall station, the rainfall potential per hour and rainfall mass within five heavy storm periods are indicated from Table 4 to Table 8, respectively.

Table IV shows the rainfall mass of about 567.5 mm within 24 hours for the 2001Trami. On 11 July from 18 to 21 o'clock, within 3 hours of heavy rain period, the rainfall mass reaches 328.5 mm, which is 58 percent of the total rainfall mass within 24 hours. Furthermore, on 11 July from 18 to 24 o'clock, the rainfall mass within 6 hours of heavy rain period reaches 427 mm, which is 75 percent of the total rainfall mass within 24 hours. Rainfall of 2011Trami is extremely concentrated in short rainfall period.

TABLE IV
RAINFALL POTENTIAL PER HOUR AND RAINFALL MASS OF 2001TRAMI. (UNITS: MM)

Time (o'clock)	Rainfall potential per hour	Rainfall mass	Time (o'clock)	Rainfall potential per hour	Rainfall mass
(7/11)6~7	1.5	1.5	18~19	95.0	104.5
7~8	1.5	3.0	19~20	107.0	211.6
8~9	0.0	3.0	20~21	126.5	338.0
9~10	1.5	4.5	21~22	22.0	360.0
10~11	0.0	4.5	22~23	32.5	392.5
11~12	0.5	5.0	23~24	44.0	436.5
12~13	0.0	5.0	(7/12)0~1	42.5	480.5
13~14	0.0	5.0	1~2	48.5	529.0
14~15	0.0	5.0	2~3	20.0	549.0
15~16	0.5	5.5	3~4	11.0	560.0
16~17	1.0	6.5	4~5	6.0	566.0
17~18	3.0	9.5	5~6	1.5	567.5

The rainfall mass of 2005Mei-Yu within 24 hours reaches 189.5 mm. The largest amount of rainfall was on 12 June from 1 to 2 o'clock and from 7 to 8 o'clock with rainfall potential per hour of 32 and 46 mm, respectively. After the two periods mentioned above, there was less rain, as exhibited in Table 5. As a result, there is no flood disaster at Benhe Village because the heavy rainfall dispersed in different periods.

TABLE V
RAINFALL POTENTIAL PER HOUR AND RAINFALL MASS OF 2005MEI-YU. (UNITS: MM)

Time (o'clock)	Rainfall potential per hour	Rainfall mass	Time (o'clock)	Rainfall potential per hour	Rainfall mass
(6/12)0~1	7.0	7.0	12~13	2.5	152.0
1~2	32.0	39.0	13~14	14.5	166.5
2~3	13.0	52.0	14~15	15.5	182.0
3~4	2.5	54.5	15~16	3.5	185.5
4~5	5.5	60.0	16~17	1.5	187.0
5~6	13.5	73.5	17~18	0.0	187.0
6~7	18.5	92.0	18~19	2.5	189.5
7~8	46.0	138.0	19~20	0.0	189.5
8~9	7.5	145.5	20~21	0.0	189.5
9~10	4.0	149.5	21~22	0.0	189.5
10~11	0.0	149.5	22~23	0.0	189.5
11~12	0.0	149.5	23~24	0.0	189.5

The rainfall mass of 2008Kalmaegi within 24 hours reached 263.5 mm. The rainfall mass was about 214 mm within 6 hours from 12 to 18 o'clock, which approaches 81 percent of rainfall mass of 2008Kalmaegi within 24 hours, as shown in Table 6. Although the rainfall potential of 2008Kalmaegi is concentrated, the rainfall mass is much less than that of 2001Trami within 24 hour.

TABLE VI
RAINFALL POTENTIAL PER HOUR AND RAINFALL MASS OF 2008KALMAEGI. (UNITS: MM)

Time (o'clock)	Rainfall potential per hour	Rainfall mass	Time (o'clock)	Rainfall potential per hour	Rainfall mass
(7/17)0~1	0.0	0	12~13	16.5	49
1~2	0.0	0	13~14	52.5	101.5
2~3	0.0	0	14~15	45.0	146.5
3~4	0.0	0	15~16	56.0	202.5
4~5	0.5	0.5	16~17	25.0	227.5
5~6	0.5	1	17~18	19.0	246.5
6~7	2.0	3	18~19	10.5	257
7~8	11.5	14.5	19~20	6.5	263.5
8~9	14.5	29	20~21	0.0	263.5
9~10	0.0	29	21~22	0.0	263.5
10~11	0.0	29	22~23	0.0	263.5
11~12	3.5	32.5	23~24	0.0	263.5

The rainfall mass of 2009Morakot within 24 hours reached 491.0mm. There were twelve rainfall potentials per hour more than 20 mm for the 2009Morakot. The rainfall potential of 2009Morakot was uniformly separated by hours, which was different from rainfall concentration phenomenon of 2001Trami. The rainfall potential per hour and rainfall mass of 2008Kalmaegi are indicated in Table 7.

TABLE VII
RAINFALL POTENTIAL PER HOUR AND RAINFALL MASS OF 2009MORAKOT. (UNITS: MM)

Time (o'clock)	Rainfall potential per hour	Rainfall mass	Time (o'clock)	Rainfall potential per hour	Rainfall mass
(8/7)22~2	18.0	18.0	10~11	9.0	317.0
23~24	18.5	36.5	11~12	22.0	339.0
(8/8) 0~1	22.5	59.0	12~13	42.5	381.5
1~2	29.5	88.5	13~14	11.0	392.5
2~3	27.0	115.5	14~15	5.0	397.5
3~4	25.0	140.5	15~16	8.0	405.5
4~5	18.5	159.0	16~17	7.5	413.0
5~6	21.5	180.5	17~18	19.5	432.5
6~7	17.0	197.5	18~19	14.5	447.0
7~8	21.0	218.5	19~20	20.0	467.0
8~9	25.0	243.5	20~21	8.5	475.5
9~10	64.5	308.0	21~22	15.5	491.0

The rainfall mass of 2010Fanapi within 24 hours is 593.5 mm, which is 27 mm more than the rainfall mass of 2001Trami within 24 hours. Rainfall potential with 12 hours from 12 to 24 o'clock on 9 September was 493.5 mm, which was the 83 percent of rainfall mass within 24 hours for 2010Fanapi and which was equal to the rainfall mass of 2009Morakot within 24 hours. The rainfall potential per hour and rainfall mass of 2010Fanapi are expressed in Table VIII.

TABLE VIII
RAINFALL POTENTIAL PER HOUR AND RAINFALL MASS OF 2010FANAPI. (UNITS: MM)

Time (o'clock)	Rainfall potential per hour	Rainfall mass	Time (o'clock)	Rainfall potential per hour	Rainfall mass
(9/19)8~9	5.0	8.0	20~21	35.5	455.0
9~10	4.0	12.0	21~22	39.5	494.5
10~11	8.0	20.0	22~23	13.0	507.5
11~12	15.5	35.5	23~24	21.0	528.5
12~13	24.0	59.5	(9/20)0~1	8.5	537.0
13~14	40.0	99.0	1~2	10.5	547.5
14~15	44.0	143.0	2~3	15.0	562.5
15~16	87.5	230.5	3~4	12.5	575.0
16~17	66.0	296.5	4~5	6.0	581.0
17~18	52.5	349.0	5~6	4.5	585.5
18~19	32.0	381.0	6~7	5.5	591.0
19~20	38.5	419.5	7~8	2.5	593.5

According to the rainfall potential per hour and rainfall mass of 2001Trami, 2005Mei-Yu, 2008Kalmaegi, 2009Morakot, and 2010Fanapi from rainfall station, the comparison of rainfall mass within 24 hours in the heavy storm events is expressed in equation (5).

$$(\text{Fanapi}) > (\text{Trami}) > (\text{Morakot}) > (\text{Kalmaegi}) > (\text{Mei-Yu}) \quad (5)$$

The comparisons of maximum rainfall masses and average rainfall potential per hour within five heavy storm periods in different rainfall duration are indicated in Table IX.

TABLE IX
COMPARISONS OF MAXIMUM RAINFALL MASSES (MRM) AND AVERAGE RAINFALL POTENTIAL PER HOUR (ARP) WITHIN FIVE HEAVY STORM PERIODS WITH MM AND MM/HR IN UNITS, RESPECTIVELY

Heavy storm events		Rainfall duration (hours)					
		1	2	3	4	6	12
2001 Trami	MRM	127	234	329	351	427	558
	ARP	127	117	110	88	71	47
2005 Mei-Yu	MRM	46	65	78	86	99	150
	ARP	46	33	26	21	17	13
2008 Kalmaegi	MRM	56	101	154	179	214	254
	ARP	56	51	51	45	37	21
2009 Morakot	MRM	65	90	111	138	174	323
	ARP	65	45	37	35	29	27
2010 Fanapi	MRM	88	154	206	250	322	494
	ARP	88	77	69	63	54	41

In comparison with the rainfall intensity of Table 1 in different rainfall frequency and duration, and average rainfall potential of Table 9 in different rainfall duration for every heavy storm, the rainfall frequencies of five heavy storms are calculated as exhibited in Table 10. The comparative diagram of average rainfall potential in different rainfall duration and rainfall mass for the five heavy storms and rainfall intensity in different rainfall frequency and rainfall duration is shown in Fig.2.

TABLE X
RAINFALL FREQUENCY IN DIFFERENT RAINFALL DURATION WITH AVERAGE RAINFALL POTENTIAL OF DIFFERENT FOR THE HEAVY STORM EVENTS. (UNIT: YEAR)

Heavy storm events	Rainfall duration (hours)					
	1	2	3	4	6	12
2001 Trami	50-100	100-200	>200	100-200	100-200	100-200
2005 Mei-Yu	< 2	< 2	< 2	< 2	< 2	< 2
2008 Kalmaegi	2-5	2-5	10-20	10-20	10	5
2009 Morakot	2-5	2-5	2-5	5-10	5-10	10
2010 Fanapi	10-20	20	20-50	20-50	20-50	50-100

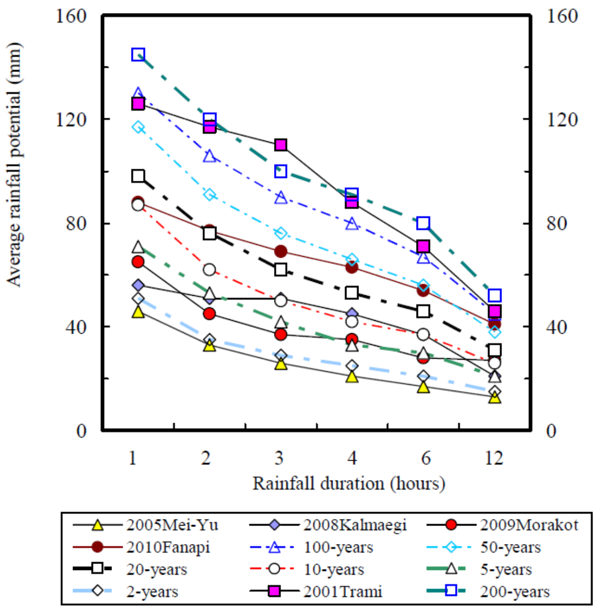

Fig.2 Comparative diagram of average rainfall potential in different rainfall duration for the five heavy storms and different rainfall frequencies

For 2001Trami, all rainfall frequencies in the rainfall duration are between 100-year and 200-year. The rainfall frequency of rainfall duration of 3-hour is even larger than 200-year. The rainfall frequencies are much more than the effluence standard of 5-year frequency for the sewerage system and flood detention standard of 20-year frequency for the Benhe flood detention pond. Rainfall potential of 2005Mei-Yu in different rainfall duration is less than that of rainfall frequency of 2-year which is smaller than that of drainage standard of sewerage system. Rainfall frequencies of

2008Kalmaegi in different rainfall duration are partly more than the drainage standard of 5-year frequency of sewerage system plan, but less than the flood prevention standard of 20-year frequency of Benhe flood detention pond. Following the above discussion, because the rainfall was distributed in average during the 2009Morakot, the rainfall potential is almost less than the flood prevention standard of 20-year frequency of Benhe flood detention pond by rainfall frequency analysis. For the 2010Fanapi, the more rainfall duration is, the more rainfall frequency is. The rainfall frequencies above rainfall duration of 2 hours are more than the flood prevention standard of 20-year frequency of flood detention

The flood detention time can be obtained by the calculation of the peak rainfall current using rationalization formula in equation (2). In comparison with Table 2 in different rainfall frequency, the runoff coefficient is acquired by using Table 10, which is substituted into equation (2), as expressed in Table 11. Part of peak currents in Table 11 are larger than the maximum drainage potential about 15.0 m^3/s of pumping system of Benhe flood detention pond, which are circled by red frame. Table 11 shows the results of calculated peak current ***Q***, which utilizes average rainfall potential of maximum rainfall mass and rainfall intensity of different rainfall frequency in different rainfall duration for heavy storm events by using rationalization formula in equation (2).

TABLE XI
PEAK CURRENT IN DIFFERENT RAINFALL DURATION AND RAINFALL FREQUENCY FOR THE HEAVY STORM EVENTS. (UNIT: M^3/S)

Peak current (m^3/s)		Rainfall duration (hours)					
		1	2	3	4	6	12
Heavy storm events	2001Trami	16.2	16.1	15.1	12.1	10.1	6.3
	2005Mei-Yu	4.6	3.4	2.7	2.2	1.7	1.3
	2008Kalmaegi	5.8	5.2	6.2	5.4	4.4	2.3
	2009Morakot	7.1	4.9	4.0	3.8	3.1	3.3
	2010Fanapi	10.6	9.3	7.5	8.0	6.9	5.3
Rainfall frequency (years)	200	20.0	16.6	13.8	12.6	11.0	7.2
	100	17.6	14.3	12.2	10.8	9.1	6.1
	50	15.0	11.6	9.7	8.4	7.2	4.9
	20	12.1	9.4	7.7	6.6	5.7	3.8
	10	10.5	7.5	6.0	5.1	4.5	3.1
	5	7.8	5.8	4.6	3.6	3.3	2.3
	2	5.3	3.6	3.0	2.6	2.2	1.5

After the peak current values of Table 11 are substituted into equation (4), the flood peak duration ***T*** of Benhe flood detention pond is achieved as exhibited in Table 12. Numbers of black words in Table 12 are meaning that flood peak duration of flood detention pond is more than rainfall duration, which the flood detention pond can sufficiently accommodate the concentrated rain potential from sewerage system. In that situation, the flood detention functioned well and there would be no flood disaster.

Numbers of blue words in Table 12 are meaning that the flood detention duration of flood detention pond is more than rainfall duration; therefore, the function of flood detention for the flood detention pond was accomplished in regular. However, the rainfall peak current is more than the maximum drainage potential about15.0 m^3/s of pumping system of Benhe flood detention pond. In practice, the rain of sewerage system will not flow into flood detention pond in time, but will flow back to the ground to make flood.

As the flood detention duration is less than the rainfall duration, the numbers of the flood peak duration is presented in red word, as shown in Table 12. When the flood detention duration is less than the rainfall duration, the flood detentiren pond will be full-load, which the flood detention pond will not possess the function of flood peak duration. In this situation, the rain water of sewerage system also flows back to ground and then the flood occurs.

TABLE XII
FLOOD PEAK DURATION OF FLOOD DETENTION POND IN DIFFERENT RAINFALL DURATION AND RAINFALL FREQUENCY. (UNIT: HOURS)

Flood peak duration (hours)		Rainfall duration (hours)					
		1	2	3	4	6	12
Heavy storm events	2001Trami	1.7	1.7	1.8	2.3	2.7	4.4
	2005Mei-Yu	5.8	8.2	10.3	12.5	16.2	21.4
	2008Kalmaegi	4.8	5.3	4.5	5.2	6.3	12.0
	2009Morakot	3.9	5.6	6.9	7.4	9.1	8.5
	2010Fanapi	2.6	3.0	3.7	3.5	4.0	5.3
Rainfall frequency (years)	200	1.4	1.7	2.0	2.2	2.5	3.9
	100	1.6	1.9	2.3	2.6	3.1	4.6
	50	1.9	2.4	3.0	3.3	3.9	5.7
	20	2.3	3.0	3.6	4.2	4.9	7.2
	10	2.7	3.7	4.6	5.5	6.2	8.8
	5	3.6	4.8	6.0	7.7	8.5	12.1
	2	5.3	7.7	9.3	10.5	12.8	18.3

Furthermore, three assumptions are established in this paper. Firstly, during rainfall period, the rain water of Benhe flood detention pond is injected from regulating pond, but not flow into the sewerage strung line. The second, if the rainfall peak current is more than 15.0m^3/s in which the five pumping machines work in full-load, calculated by equation (4), the Benhe flood detention pond is with flood peak duration no more than 1.9 hours. The third, because the limitation of pumping capability of pumping machines, the residuary rain water in regulating pond which is not pumped to flood detention pond will flow back to the ground and then will result in flood disaster.

As indicated in Table 11 and Table 12, if the peak current of 2001Trami in rainfall duration of one hour with maximum rainfall mass reaches 16.2 m^3/s which is more than the maximum drainage potential about 15.0m^3/s of pumping system of Benhe flood detention pond, the flood peak duration of flood detention pond is just 1.7 hours. The other rainfall durations are still more than the flood detention capability of flood detention pond. Therefore, if the Benhe flood detention pond was constructed before 2001Trami, the flood detention pond would still overflow before rainfall time reached 1.7 hours. The rainfall masses of 2005Mei-Yu and 2008Kalmaegi in different rainfall duration are all less than the flood detention capability of flood detention pond. In practice, no flood disasters occurred in 2005Mei-Yu and 2008Kalmaegi events. Table 11 exhibits the rainfall peak currents in both 50-year to 200-year rainfall frequency of 1-hour rainfall duration and 200-year rainfall frequency of 2-hour rainfall duration which exceed the maximum drainage potential about 15.0m^3/s of pumping system of Benhe flood detention pond. In this rainfall condition, the rainwater of sewerage system would not flow into flood detention pond and then flow back to ground, in which the flood disaster happened.

Rainfall mass of 2009Morakot in less than rainfall duration of 12 hours is lower than capability of Benhe flood detention, as exhibited in Table 12. Eventually, the flood disaster didn't occur at Benhe Village even though the rainfall mass in rainfall duration of 12 hours exceeds capability of Benhe flood detention. The cause is that the rainfall potential of 2009Morakot didn't concentrate in short rainfall period and the rainfall peak current was low. In this rainfall situation, the river and K sewerage strung line were not full-load, the water of flood detention pond would be drained into the river and K sewerage strung line. Therefore, even though the rainfall mass in rainfall duration of 12 hours is more than capability of Benhe flood detention pond, the flood disaster wouldn't take place in practice. Rainfall mass of 2010Fanapi in more than rainfall duration of 4 hours is larger than capability of Benhe flood detention pond, as indicated in Table 12, in which the flood peak duration of flood detention pond is only 3.5 hours, that is, flood disaster would come after 4 hours. Although the rainfall mass of 2010Fanapi in rainfall duration of 24 hours is more than that of 2001Trami, the flood peak duration of flood detention pond is more than that of 2001Trami. As a result, the key factors of flood disaster are not only total rainfall mass, but also rainfall frequency of heavy storm in differential rainfall duration and flood prevention frequency of flood prevention system. The rainfall conditions as shown in the red and blue data of Table 12 indicate that the Benhe flood detention pond is only with capability of flood peak duration, but not flood detention completely.

On the whole, the influence of flood detention pond in flood peak duration is studied by using peak current data, in which the interaction between other drainage system, sewerage system, and other flood detention ponds is not considered. Base on the data and studies as above, to solve the problem of flood disaster, the new model, which is called stable flood detention model (SFD model), is constructed in this paper. The SFD model is constructed by using the system dynamic theory. Before the flood detention pond is not yet established, the sewerage system is the only drainage system, which is unstable system for drainage of rainfall and flood. The drainage system without flood detention pond is called traditional flood detention system. The traditional flood detention system is an open loop system and is a divergence system, defined in system dynamic theory, because of its unstable rainfall potential and drainage potential in time variable, as exhibited in Fig. 3.

In Fig.3, the $\mathbf{S_i(t)}$ and $\mathbf{S_o(t)}$ are the rainfall potential variable and drainage potential variable, respectively. The $\boldsymbol{f_S}$, flood detention function of traditional flood detention system, depends on the drainage function $\mathbf{V_S(t)}$ of sewerage system. The $\mathbf{C_S}$ is a drainage system constant of sewerage system. The flood detention function is proportional to time variable. In this traditional flood detention system, when the $\mathbf{S_o(t)}$ is more than $\mathbf{S_i(t)}$, the over drainage occurs. When the $\mathbf{S_o(t)}$ is less than $\mathbf{S_i(t)}$, the under drainage phenomenon occurs, which will result in flood disaster. Therefore, the traditional flood detention system is an unstable drainage system.

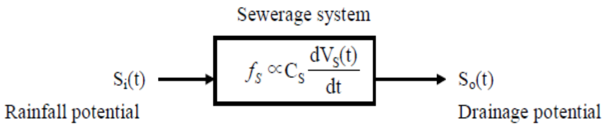

Fig. 3 The traditional flood detention system

The well-defined drainage system with flood detention pond, so called stable flood detention model (SFD model) is established in this paper, as exhibited in Fig. 4. The traditional sewerage system is paralleled in flood detention system to stabilize the functions of water storage and flood control. The flood detention system is as a feedback system of the SFD model. When the whole system is including feedback system, the whole system, which is a close loop system, will possess well-defined stable phenomenon in flood control.

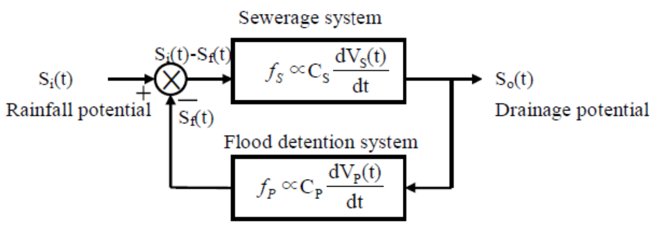

Fig.4 The stable flood detention model (SFD model)

$\mathbf{S_i(t)}$ and $\mathbf{S_o(t)}$ of Fig.4 are also the rainfall potential variable and drainage potential variable, respectively. The $\boldsymbol{f_S}$, $\mathbf{C_S}$, and $\mathbf{V_S(t)}$ are the same as the traditional flood detention system. The $\boldsymbol{f_p}$, flood detention function of flood detention system, depends on the drainage function $\mathbf{V_p(t)}$ of flood detention system. The $\mathbf{C_p}$ is a drainage system constant of flood detention system. The drainage function of flood detention system is also proportional to time variable. The time variable is proportional to rainfall duration and flood detention duration.

In this SFD model, either $\mathbf{S_o(t)}$ more than $\mathbf{S_i(t)}$ or $\mathbf{S_o(t)}$ less than $\mathbf{S_i(t)}$, the over drainage phenomenon is only occurred, which will not result in flood disaster. Therefore, the SFD model is a stable and convergence drainage system in flood control. The flood control function $\boldsymbol{f_{SFD}}$ is defined in equation (6).

$$f_{SFD} = \frac{f_S}{1 + f_P f_S} \tag{6}$$

The drainage magnitude of flood control function $\boldsymbol{f_{SFD}}$ is less than that of traditional drainage function $\boldsymbol{f_S}$. However, the duration function of SFD model is better than that of traditional flood detention system, because of its flood control stability.

V. Conclusions

Although the rainfall mass of 2010Fanapi within 24 hours is more than that of 2001Trami, flood detention duration of flood detention pond is more than flood peak duration of 2001Trami. Not only rainfall mass, but also rainfall frequency of heavy storm in different rainfall duration and flood detention frequency of flood detention system are the key factors of flood disaster. Because the flood detention capability of flood detention pond possesses a limitation, when rainfall frequency is less than flood detention capability, the flood detention pond can delay the rainfall peak current, but not completely obstructing flood disaster. Some research results are concluded in this paper as follow.

1. Rainfall potential of 2001Trami exceeded the rainfall frequency of 100-year, even it exceeded the rainfall frequency of 200-year. If the Benhe flood detention pond had been built before 2001Trami event happened, the flood detention pond within rainfall time of 1.7 hours would still be full-load and overflow.
2. When the rainfall frequency of 2010Fanapi in above rainfall duration of 3 hours is more than flood prevention standard of sewerage system and flood detention standard of Benhe flood detention pond, the flood peak duration of flood detention pond is 3.5 hours at most. The flood disaster would occur due to too much rainfall but not unable flood detention pond.
3. Parts of rainfall frequency of 2008Kalmaegi and 2009Morakot were higher than drainage standard of 5-year rainfall frequency of sewerage system, but all of rainfall frequency of 2008Kalmaegi and 2009Morakot were lower than flood detention standard of 20-year rainfall frequency of Benhe flood detention pond. Therefore, the flood detention function of flood detention pond was accomplished, in which the flood disaster was eliminated.
4. The rainfall frequency of 2005Mei-Yu was less than drainage standard of 5-year rainfall frequency of sewerage system, which was the reason of why no flood disaster.
5. If the peak current of rainfall is more than the maximum drainage potential of pumping system of Benhe flood detention pond about $15.0m^3/s$, the flood peak duration flood detention pond is 1.9 hours at most. However, because of limitation of pumping capability, the rain water not pumped into flood detention pond would flow back to the ground and then result in flood disaster.
6. The flood detention pond is a buffer system with function of flood peak duration. The flood detention pond is the key factor of stable drainage and flood control which is proposed by SFD model in this paper.

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References

[1] L. M. Nhat, Y. Tachikawa, T. Sayama, and K. Takara, "Regional rainfall intensity-duration-frequency relationships for ungauged catchments based on scaling properties," Annuals of Disas., Prev. Res. Inst., vol. 50(B), pp.33-43, April. 2007.

[2] Monthly Report on Climate System, Central Weather Bureau, Ministry of Transportation and Communications, Taiwan, Republic of China, 2001-2010.

[3] H. L. Wu and Z. Y. Feng, "Ecological engineering methods for soil and water conservation in Taiwan," Ecological Engineering, vol. 28, pp. 333-344, Sept. 2006.

[4] A. Katimon and A. K. A. Wahab," Hydrologic characteristics of a drained tropical peat catchment: runoff coefficients, water table and flow duration curves," Jurnal Teknologi, vol. 38(B), pp. 39-54, Jun. 2003.

[5] R. Acar and S. Şenocak,"Modelling of Short Duration Rainfall (SDR) Intensity Equations for Ankara,"International Conference of Water Observation and Information System for Decision Support (BALWOIS 2008), pp. 1-9, May 2008.

[6] K. T. Lee, "Critical rainfall duration for maximum discharge from overland plane," J. Hydraulic Engrg., vol.120(12), pp.1480-1484, 1994.

[7] The First National Urban Flood Detention Pond Wetland Park, Sewerage System Department of Public Works Bureau, Kaohsiung City Government, Taiwan, Republic of China, 2005.

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